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Title: Supernova Neutral Current Signal in 40Ar

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Supernova Neutral Current Signal in ^{40}Ar

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Abstract

We present calculations for the expected supernovae neutrino signals in a liquid argon neutrino detector. We compare these to the signals expected on carbon. In general, to extract the SN physics more than one signals is needed.

At Supernova Neutrino Energies E_ν~0-50 MeV GT Transitions Dominate

$$\sigma_\nu = \frac{G_F^2 g_A^2}{\pi} \left\langle f \left\| \vec{\Sigma}(q) \right\| i \right\rangle^2 , \vec{\Sigma} = \vec{\sigma}\vec{\tau}$$

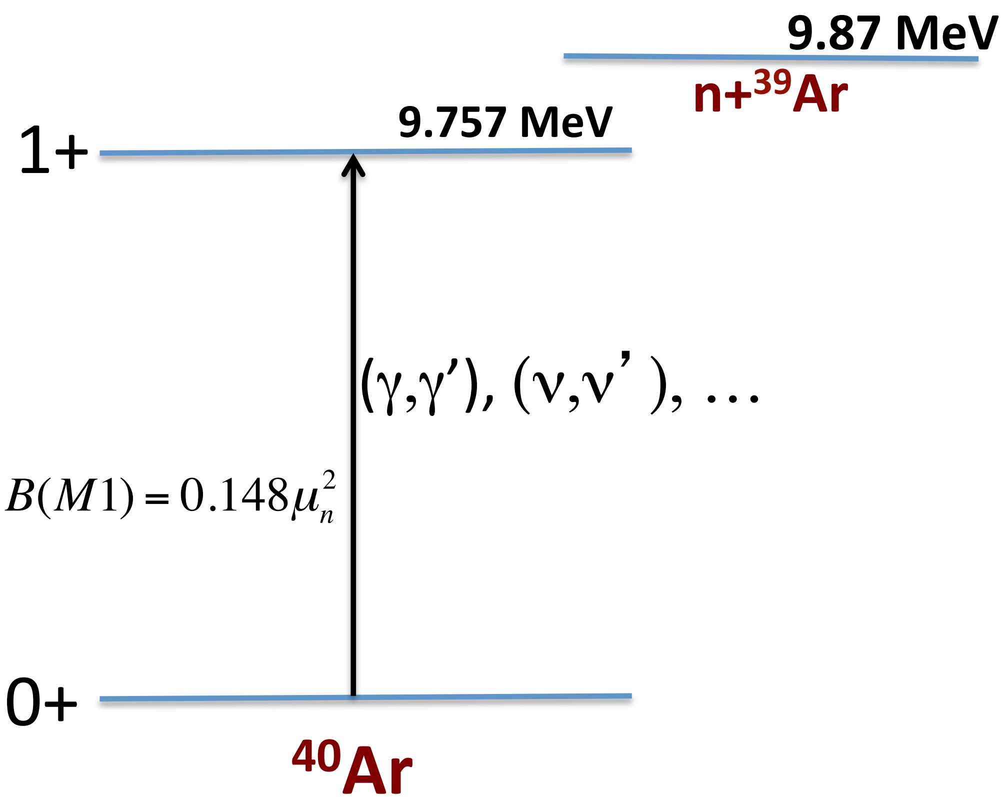
$$\xrightarrow{q=0} \frac{G_F^2 g_A^2}{\pi} B(GT)$$

B(GT) can be approximated by the B(M1) gamma-ray strength, if the γ-transition is almost pure spin-flip

$$B(GT) = \frac{1}{2}\left\langle \sigma\tau \right\rangle^2$$

$$B(M1) = \frac{3}{4\pi}\left\{ g_l^{IS}\left\langle \ell \right\rangle + \frac{g_s^{is}}{2}\left\langle \sigma \right\rangle + \frac{g_s^{IV}}{2}\left\langle \ell\tau \right\rangle + \frac{g_s^{IV}}{2}\left\langle \sigma\tau \right\rangle \right\}^2 \mu_n^2$$

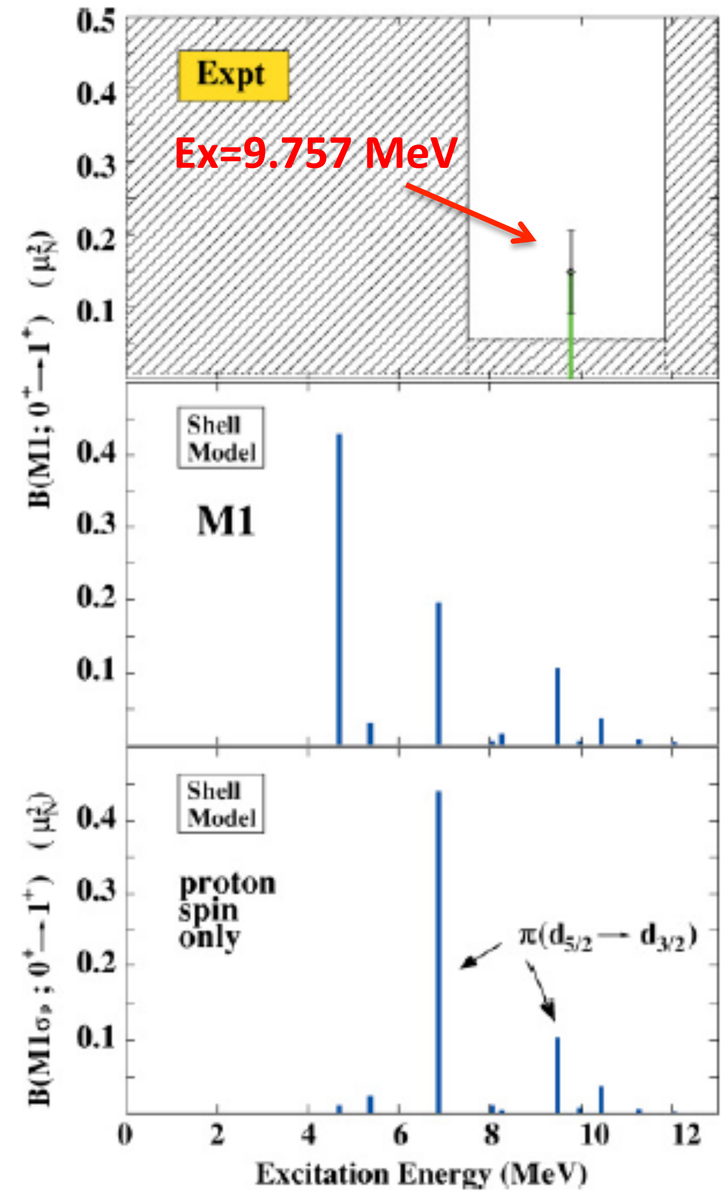
Almost Pure Spin-flip M1 State in ^{40}Ar at 9.757 MeV



$$B(M1) = 0.148\mu_n^2 \ ,$$

and pure $d_{5/2} \rightarrow d_{3/2}$ proton spin-flip

$$\Rightarrow B(GT) = 0.0418$$



1. Q-dependence of the form factors lowers cross section
2. Weak magnetism gives a ~20% difference between ν & $\bar{\nu}$

Four operators determine the neutral cross section to the 9.757 MeV 1^+ in ^{40}Ar

$$T^{mag}_{J=1M} = \frac{q}{M_n}\left[F_1^V \Delta_{J=1}(q) - \tfrac{1}{2}\mu^V \Sigma'_{J=1}(q)\right]$$

$$M^5_{J=1} = \frac{q}{M_n}\left[F_A \Omega_{J=1}(q) - \tfrac{1}{2}(F_A - \omega F_p)\Sigma''_{J=1}(q)\right]$$

$$L^5_{J=1} = \left[F_A - \tfrac{1}{2}\left(\frac{q}{M_N}\right)^2 M_N F_p\right]\Sigma''_{J=1}(q)$$

$$T^{el5}_{J=1} = F_A \Sigma'_{J=1}(q)$$

$$\langle d_{3/2} \| \Delta \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}}\sqrt{10}\,\frac{1}{5}\left(1 - \frac{2}{5}y\right)\exp(-y)$$

$$\langle d_{3/2} \| \Sigma' \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}}\sqrt{10}\,\frac{4}{5}\left(1 - \frac{11}{10}y + \frac{1}{5}y\right)\exp(-y)$$

$$\langle d_{3/2} \| \Sigma'' \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}}\sqrt{5}\,\frac{4}{5}\left(1 - \frac{9}{5}y + \frac{2}{5}y^2\right)\exp(-y)$$

$$\langle d_{3/2} \| \Omega' \| d_{5/2} \rangle = \frac{1}{\sqrt{4\pi}}\sqrt{5}\left(1 - \frac{2}{5}y\right)\exp(-y)$$

$$y = (bq/2)^2$$

=> At Eν~ 25 MeV cross section drops below the simple $\dfrac{G_F^2 g_A^2}{\pi} B(GT)$

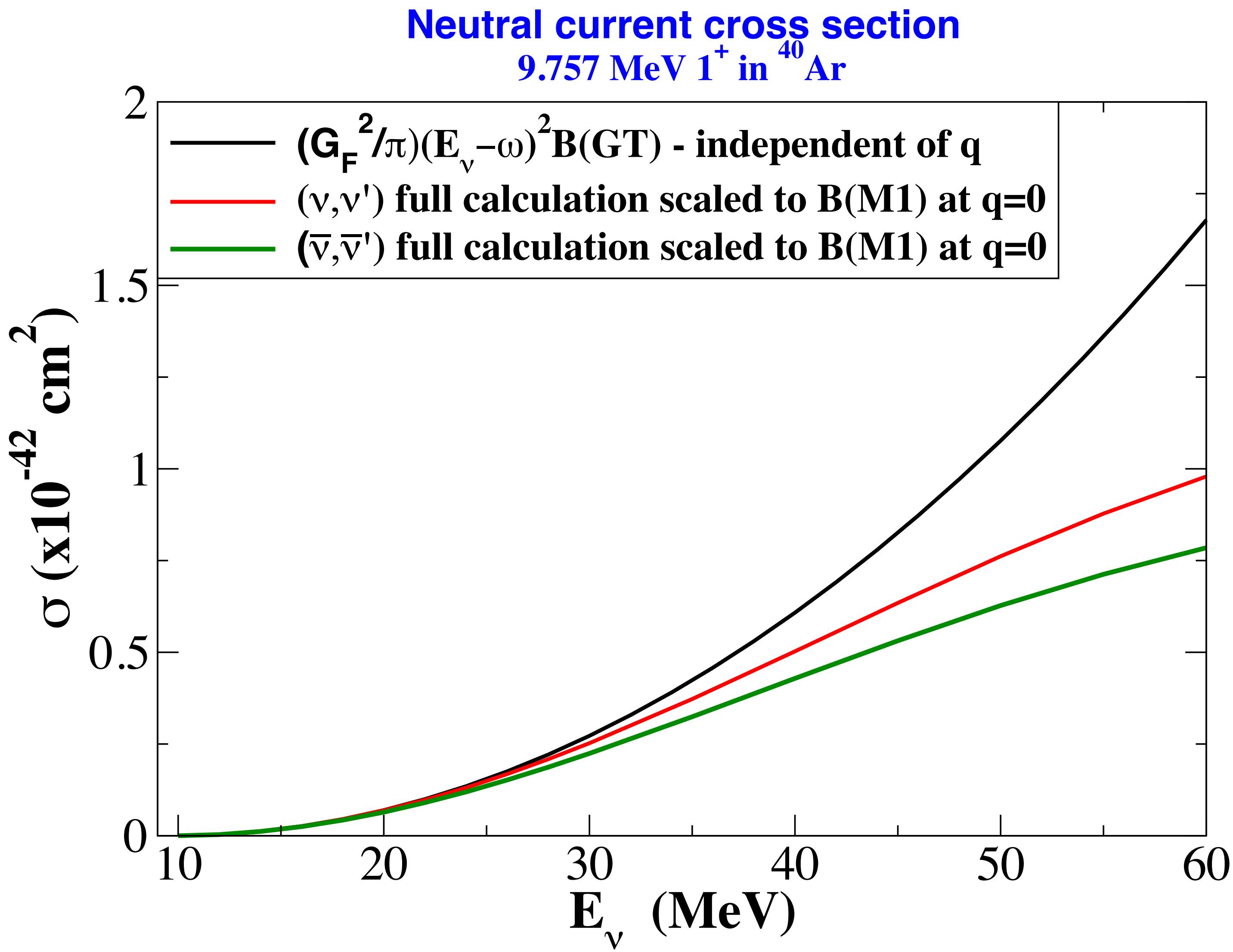
2. Weak magnetism gives a ~20% difference between ν & $\bar{\nu}$

Interference term has opposite sign fo neutrino versus antineutrino

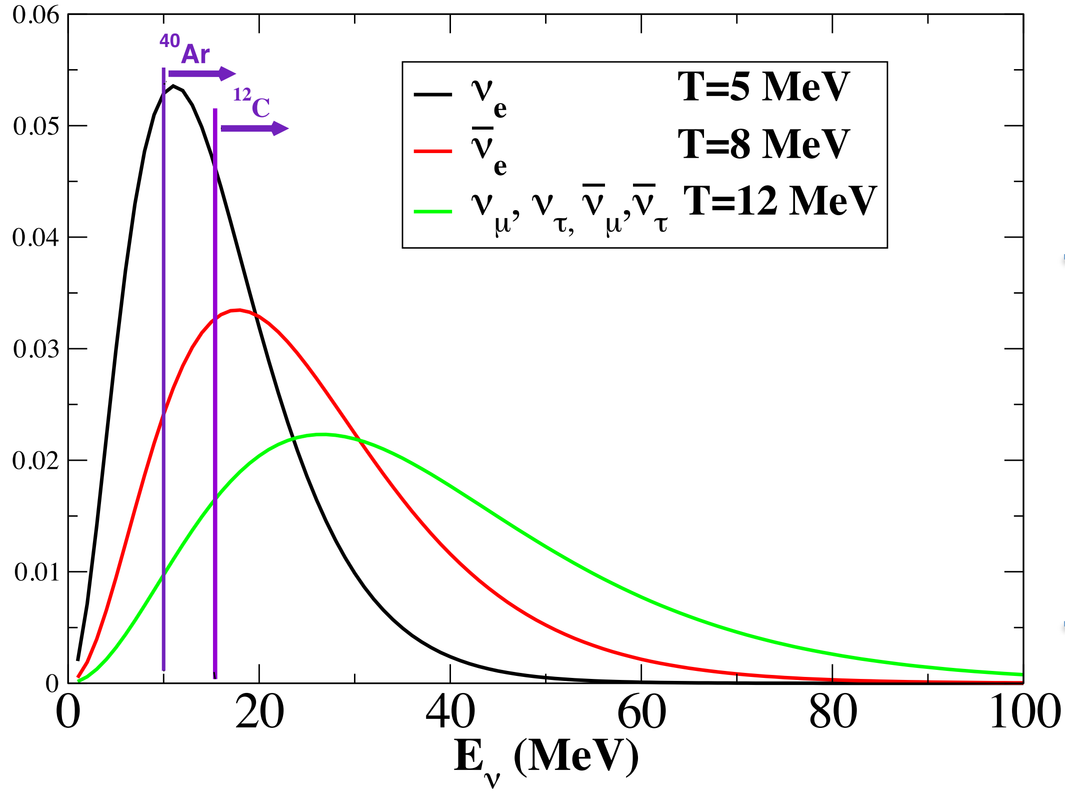
$$\sim \pm T_V^{mag}(q) T_A^{el}(q)$$

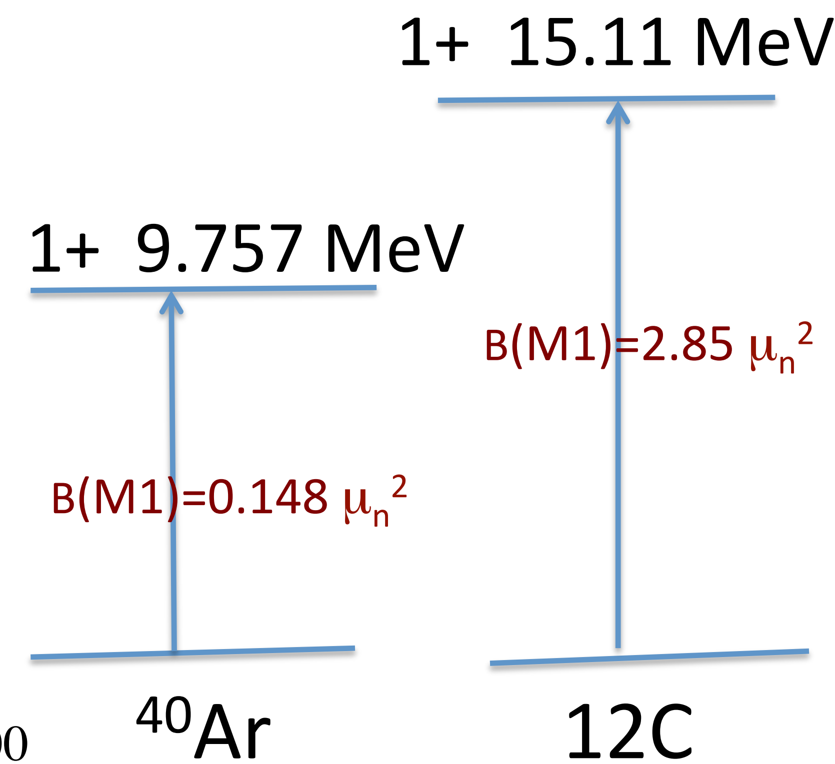
=> Neutrino and anti-neutrino cross sections deviate at Eν ~ 25 MeV

Predicted Cross Sections



Fermi-Dirac Neutrino Flux – No Oscillations



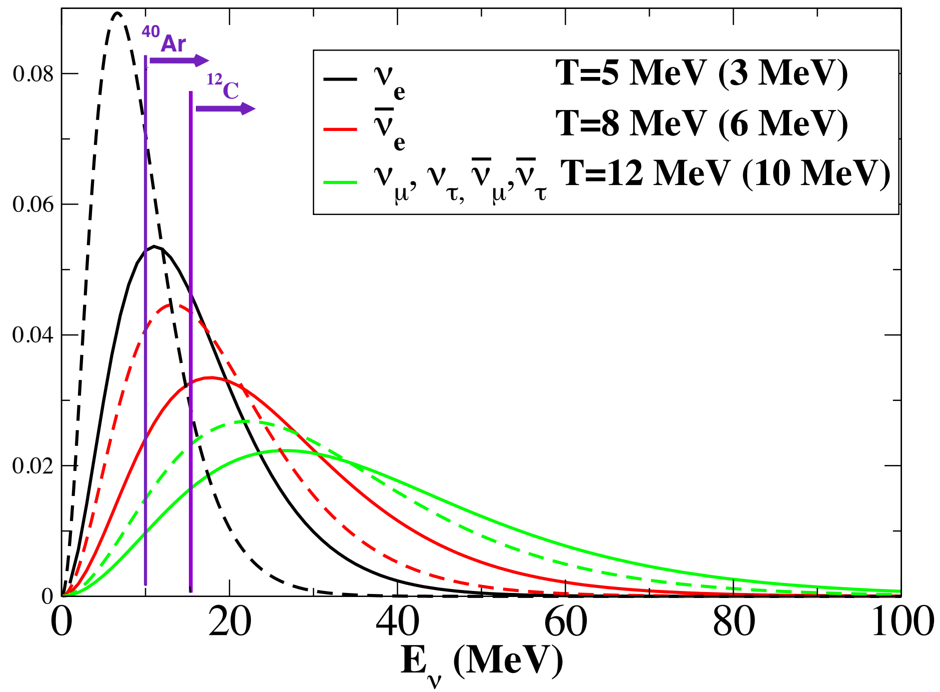


Total Cross section (all 6 neutrinos flavors)

^{40}Ar $1.1\text{x}10^{-42}$ cm^2 < Eν> =44 MeV

^{12}C $16.0\text{x}10^{-42}$ cm^2 < Eν> =48.8 MeV

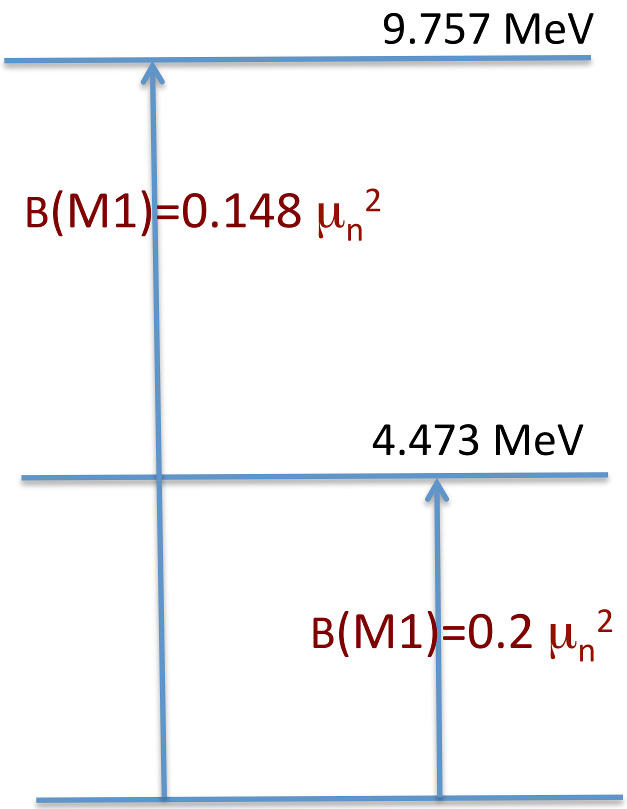
SN Neutrino Temperature Uncertain



ν_e **3-15% - also measured via CC**

	σ ^{40}Ar X10^{-42} cm^2 T>	T<	<Eν> MeV T>	T<	σ ^{12}C X10^{-42}cm^2 T>	T<	<Eν> MeV T>	T<
ν_e	.07	.01	30	22	.6	0 .05	35	26.
$\nu_{e\text{-bar}}$	.18	.1	41	34	2.4	1.0	46	38
$\nu_{\mu,\tau\text{-bar}}$	.37	.34	53	49	5.8	4.1	57	52
$\nu_{\mu,\tau}$	.45	.3	52	48	7.3	5.0	58.	53

Additional Neutral Current Signal in ^{40}Ar at 4.473 MeV



9.757 MeV state almost pure d5/2→ d3/2
=> (ν,ν) cross section straightforward

4.473 MeV structure unknown
- Needs more work
- Emitted gamma –ray could confuse $(\nu_e$,e-) signal

To be done

- Neutral current signals of different SN temperatures, etc.
- Charged current cross sections (including q-dependent form factors) and signatures
- Breakup of nucleus with neutron emission
- Analysis of signals in different detectors, water Cherenkov, etc. to max extraction of SN physics